BOND CHARACTERISTICS OF COMMERCIAL AND PREPARED REINFORCING BARS

Second Progress Report
on
Research Project C-18

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INTRODUCTION

Research Project C-18 was designed for the purpose of making comparisons of the bond characteristics of commercial and prepared bars of reinforcing steel for horizontal and vertical positions of casting. The data includes tests made for bars cast in concretes of both low and high slumps. The project was started March 26, 1945, but is not complete to the extent as was originally planned, since only two of the five types of bars employed have been cast in high slump concrete.

The data presented in this report includes test results for eight sets of specimens designated as Series A through Series G, inclusive. Each series consisted of six bars of the same type of deformation, thirty-six inches in length and seven-eighths inches in diameter. The bars were cast in three positions; all embedded in the concrete to depth of 10-1/2 inches (12 diameters), with approximately one-half inch protruding for the purpose of measuring the slip at the free end. Of the six bars in each set two were cast in the vertical position in a 6 x 10-1/2 inch cylinder, the bars extending upward, and the remaining four were cast in horizontal positions - two in each of two blocks 6 x 10-1/2 x 18 inches high (See Plate I for a sketch showing the method of casting).

For each horizontal casting the bottom bar was centered three inches from the bottom of the block and the top bar was centered fifteen inches from the bottom. The middle 6 x 6 inches section was later sawed out, thus leaving each horizontally cast bar centered in a block 6 x 6 x 10-1/2 inches deep. Thus, each series consisted of two bars cast in each of the vertical, bottom horizontal, and top horizontal positions for the pull-out tests, and three 6 x 12 inch

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Sketch showing method of casting

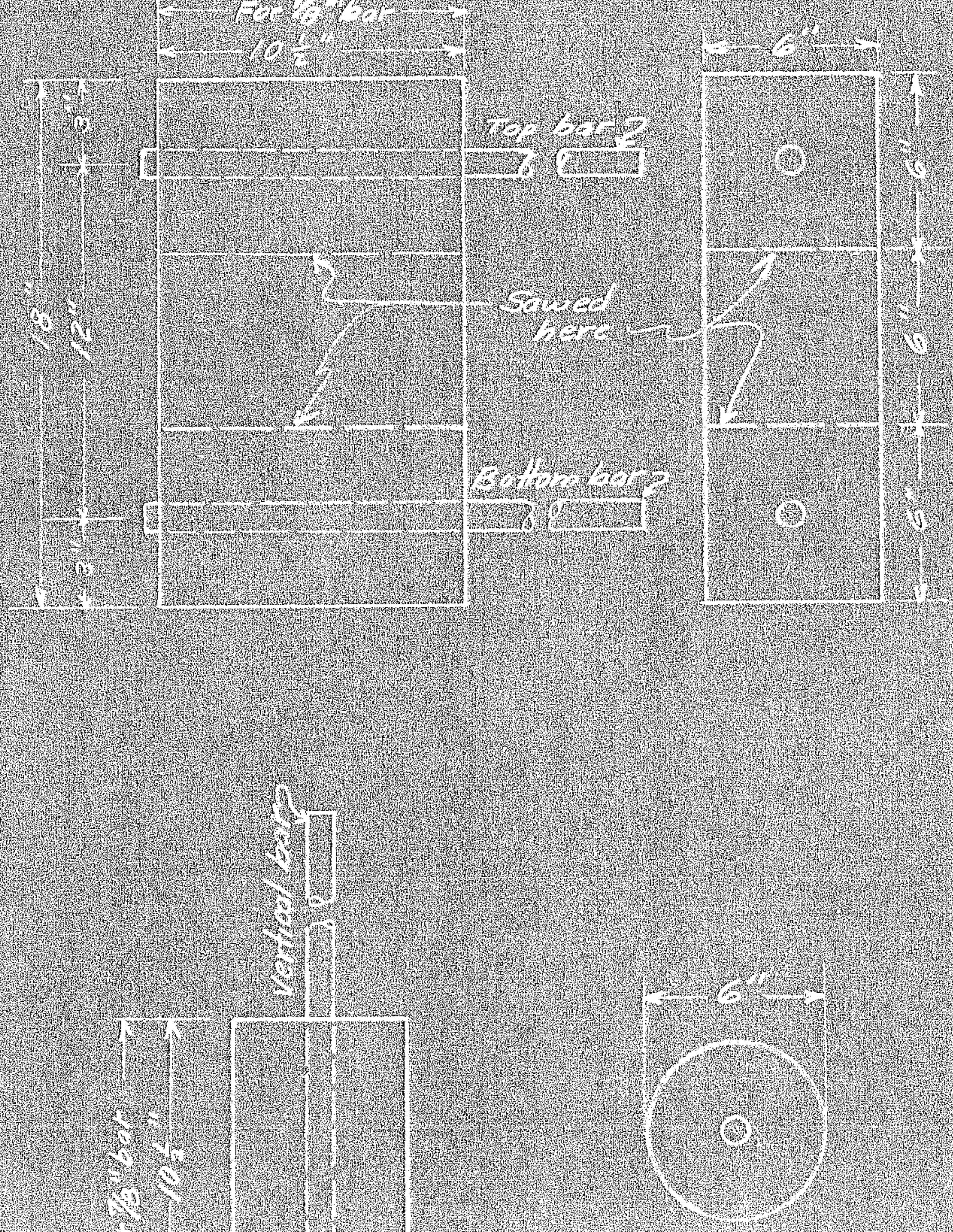


PLATE I

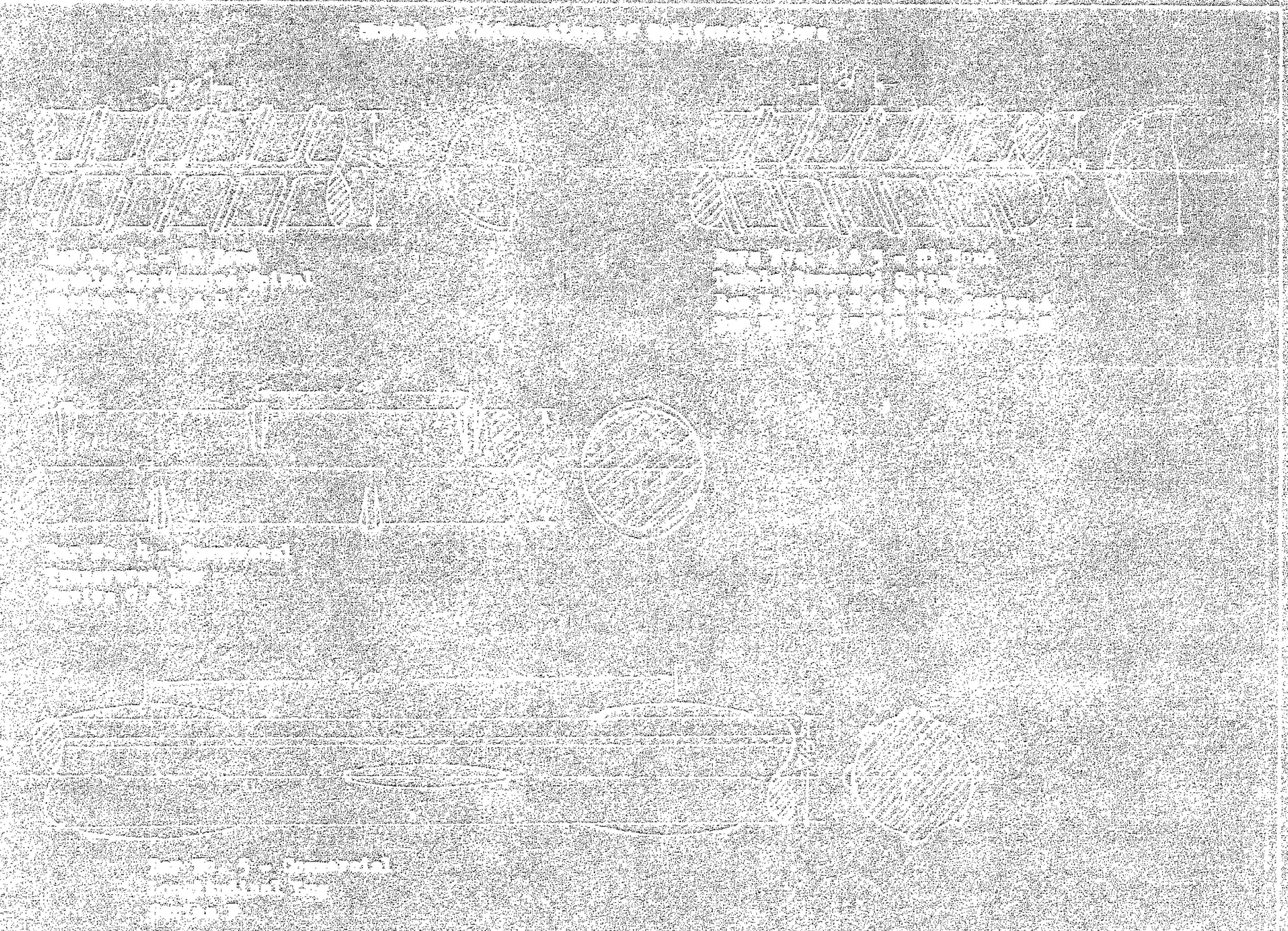
concrete cylinders for 28 day compressive strength. The results to date, then, were obtained from tests on 24 compressive-strength cylinders and 16 samples with embedded bars for measuring bond resistance.

MATERIALS

One standard brand of portland cement was used throughout the project. The fine aggregate was Ohio River concrete sand, from Cleves, Ohio, having a specific gravity of 2.65 and an absorption of 1.0 percent. The coarse aggregate was a crushed limestone, size No. 6, produced by the Central Rock Company, Lexington, Kentucky, with a specific gravity of 2.72 and an absorption of 0.6 percent.

Four of the five types of reinforcing bars used in this project were furnished by the Carnegie Illinois Steel Corporation at Pittsburgh, Pennsylvania, three of which were prepared bars bearing the trademark of Hi-Bond. The fourth was a commercial bar with transverse lugs spaced at 1.5 inches and staggered for opposite sides of the bar. The Hi-Bond prepared bars were essentially alike, the ribs forming a closely spaced double helix. For the bars referred to as a double continuous spiral, with respect to its deformation, the ribs formed a double helix spiraling continuously around the bar at 0.4 inch spacing. The two types of bars referred to as double reversed spiral differed only in the spacing of the lugs, or ribs, one having 0.4 inch spacing and the other 0.5 inch spacing. This type differed from the continuous spiral in that the direction of the helix for one side of the bar was reversed with respect to that on the opposite side. This effect is produced by reversing one of the rollers during the milling operations.

The fifth type was a commercial bar, procured from a Lexington, Kentucky, firm. Longitudinal lugs on this bar were spaced at 4.0 inches in each of four rows, and staggered in alternate rows.



See Plate II for sketches of the different type of bars.

PROCEDURE

Concrete batches were designed of sufficient size in order that one batch would fill all forms for each series. The basis for concrete design for mixes in all series is as follows:

Cement: 6 sacks per cubic yard.

Water: 6 gallons per sack of cement.

Ratio of Fine and Coarse Aggregates:

40 - 60 percent by weight.

Slump: Variable - Approximately 3 inches and approximately 6 inches.

No adjustments were made in the mix proportions to compensate for any deviation in the cement factor from the design proportions due to variations in the amount of free water added. The concrete was placed in the molds and rodded in the usual manner, care being exercised in placing the reinforcing bars normal to the face of the concrete. The series are listed in Table I with descriptions of the bars and the slump of the concrete pertaining to each.

TABLE I

Description of Reinforcing Bars with Respective Series and Concrete

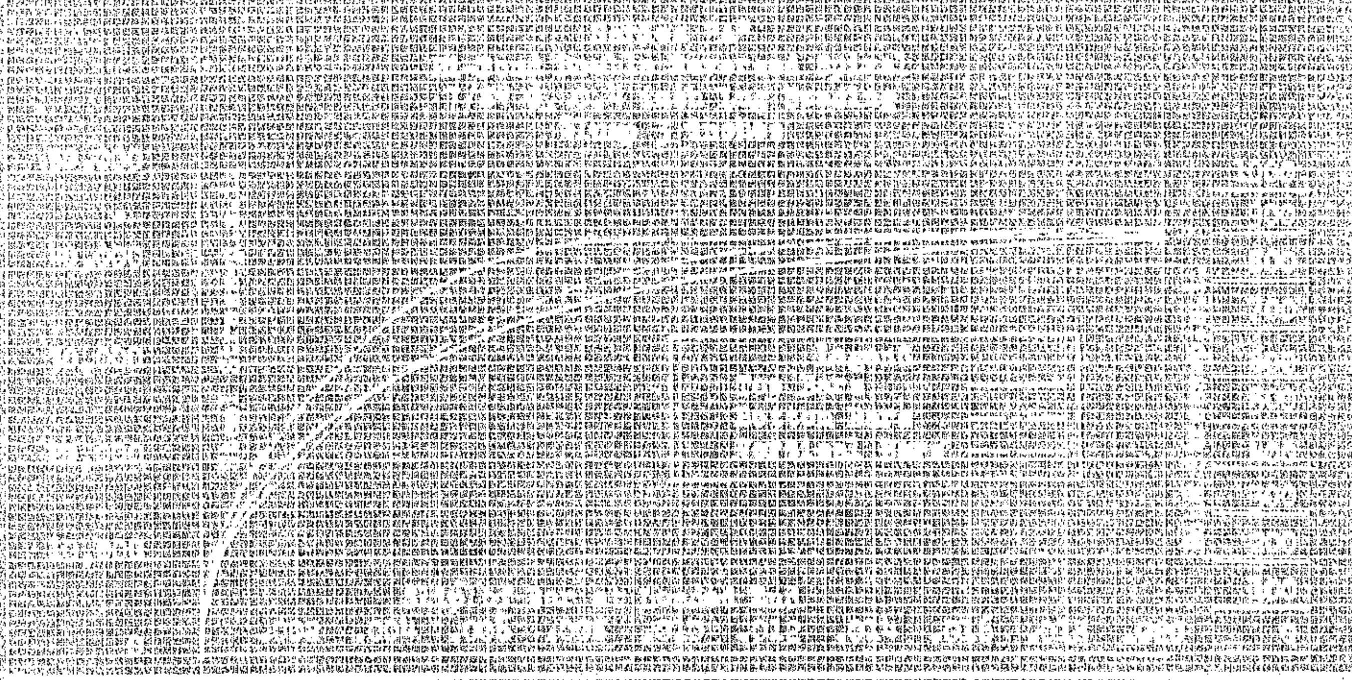
Series	Slump of Conc. inches	Description of Bars			
		Bar No.	Kind	Deformation	Lug Spacing Inches
A	3	2	Hi-Bond	Double helical Reversed spiral	0.4
B	5	1	Hi-Bond	Double helical Continuous spiral	0.4
C	3-1/2	4	Commercial	Transverse Lug	1.5
D	3-1/2	1	Hi-Bond	Double helical Continuous spiral	0.4
E	3-1/2	3	Hi-Bond	Double helical Reversed spiral	0.5
F	2-3/4	5	Commercial	Longitudinal lug	4.0
G	6	1	Hi-Bond	Double helical Continuous spiral	0.4
H	6	5	Commercial	Transverse lug	1.5

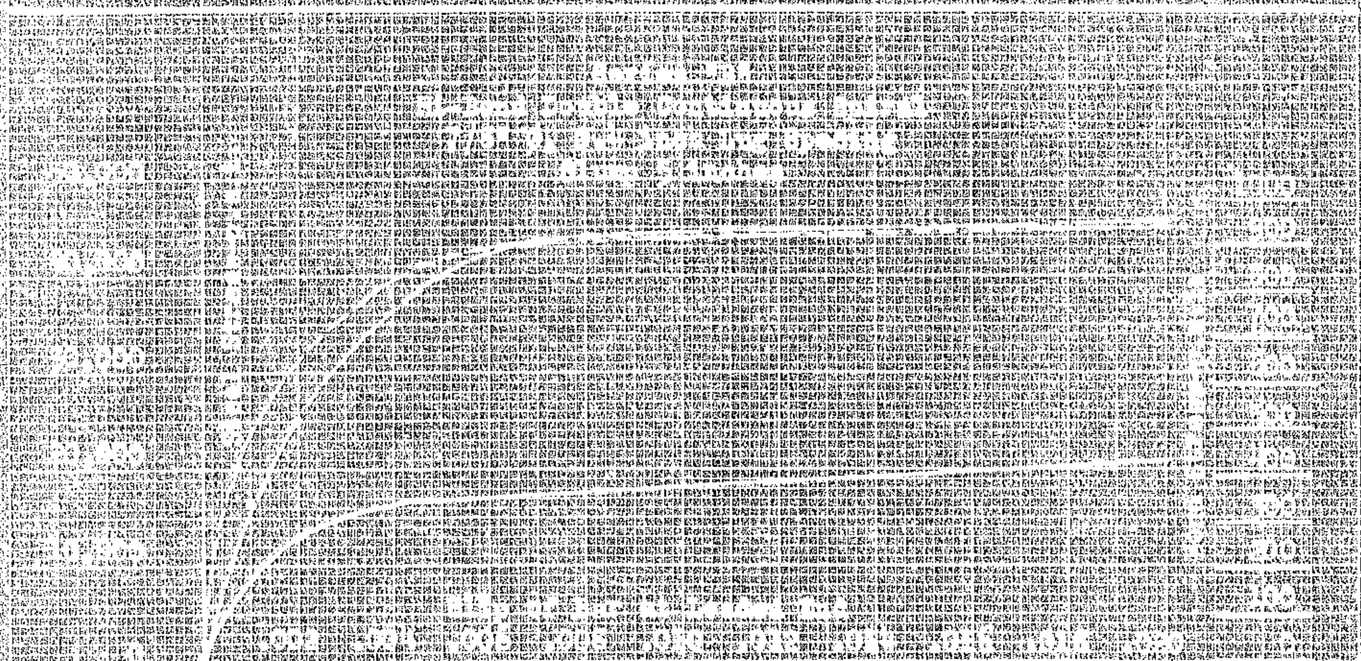
In the setup for the pull-out test, the concrete block was placed above the stationary crosshead of the testing machine, with the bar extending downward. The smooth face of the concrete, normal to the bar, was seated on a smooth plate and the bar was gripped in the jaws of the lower crosshead, twenty inches of the bar remaining between the concrete block and the jaws. A device holding an Ames dial graduated to one ten-thousandths of one inch, was fixed to the top of the concrete block with the stem of the dial in contact with short length of protuding bar. The purpose of this arrangement was to measure the slip at the free end. Beneath the stationary crosshead and gripped to the bar was another device holding two Ames dials, each graduated to one one-thousandth of one inch with the stems of the dials in contact with the lower surface of the stationary crosshead. With this arrangement the total movement was measured, including both the elongation of the bar and the slip at the loaded end for the applied load. Plate III is a sketch showing this setup.

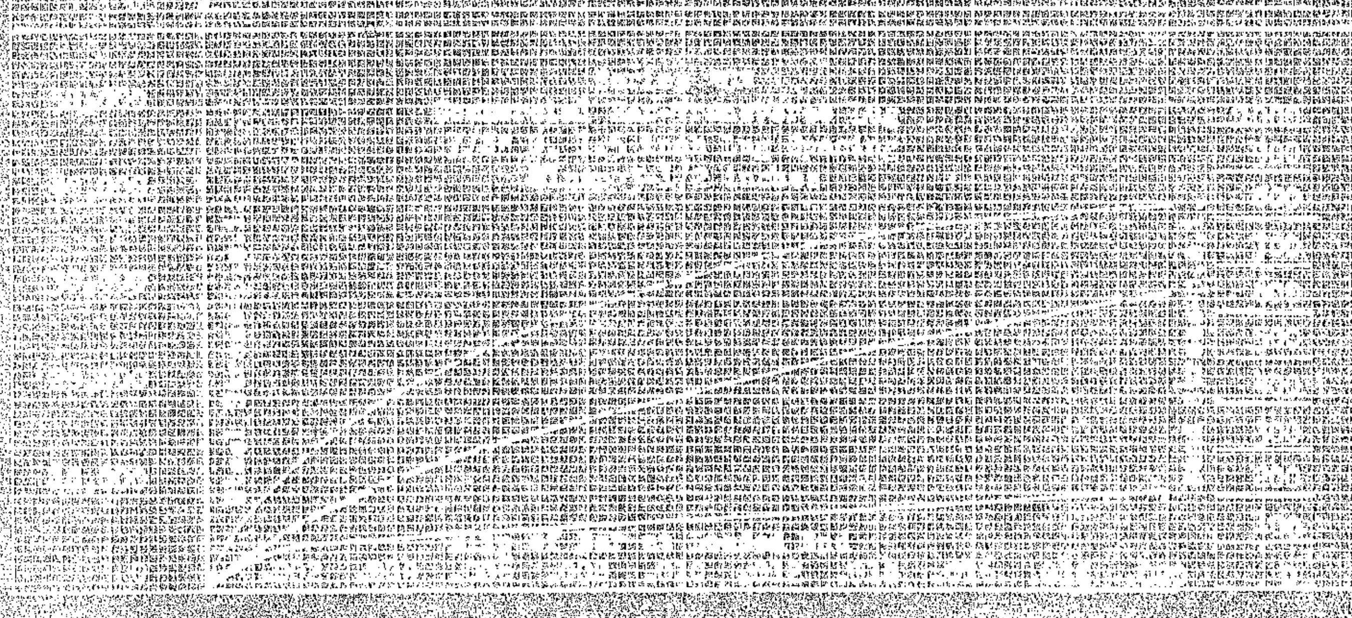
Dial readings were taken for each 1000 pounds of load up to the yield point of the steel (approximately 44,000 p.s.i.). The elongation of the steel, which had been determined previously, was deducted from the average of the two dial readings, thus, giving the slip of the bar at the loaded end for each 1000 pounds of load applied.

Load - Slip curves were plotted from the average results pertaining to each pair of top, bottom, and vertical specimens in each series - the slip in inches at the loaded end being plotted as the abscissa against the unit steel strees developed as the ordinate. The Load - Slip curves are plotted on Plates IV, V, and VI and Table II is a summary of test data.

LOAD-SLIP CURVES FOR RESEARCH PROJECT C-12







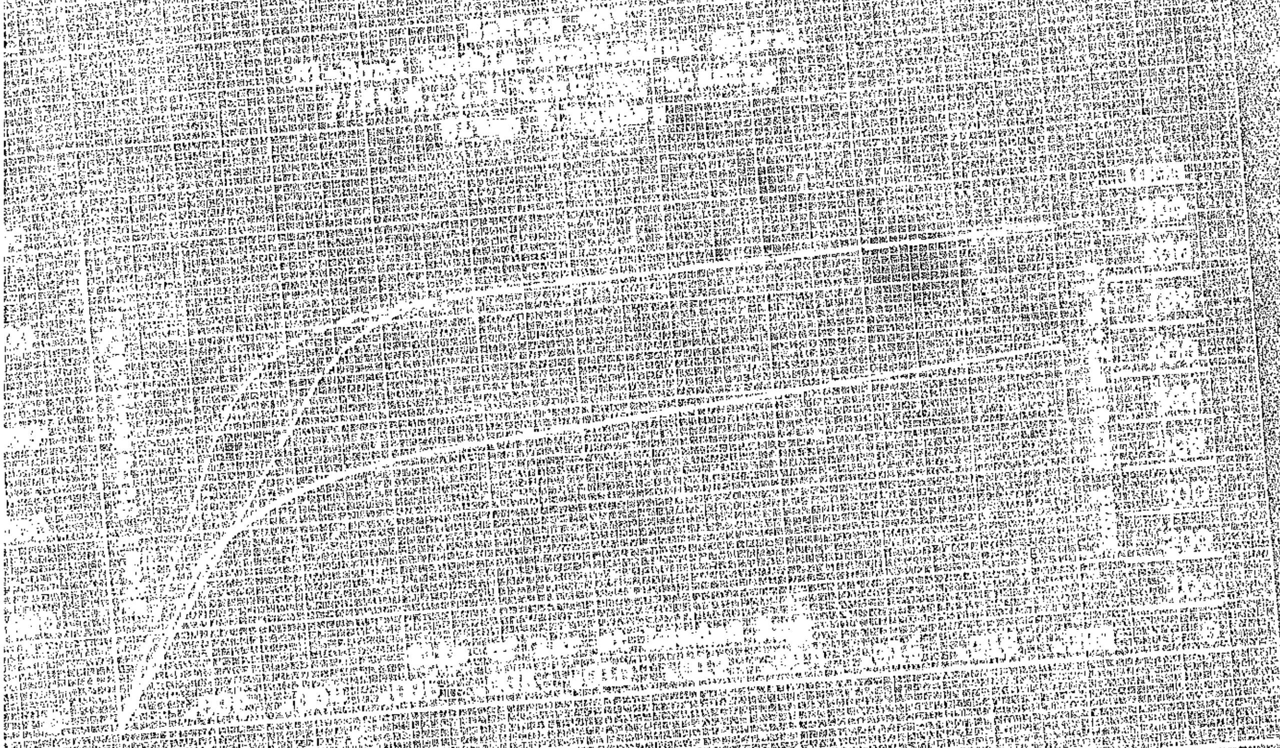


TABLE II Summary of Test Data for Research Project C-18

Series	Actual Mix: Cement	Actual Mix: Water	Actual Mix: Slump	Compr. Strength	Position of Casting	Type of Bar	Stresses Developed: Slip 0.001" Steel Str.	Stresses Developed: Free End Bond Str.	Stresses Developed: Slip 0.01" Steel Str.	Stresses Developed: Loaded End Bond. Str.
	bags / cu.yd.	gals. / bag	inches	p.s.i.	Ave.of 2		p.s.i.	p.s.i.	p.s.i.	p.s.i.
					Vertical	Double	44,000	915	40,500	840
"A"	6.048	5.42	3	5818	Bottom	Rev.	43,000	895	42,500	885
					Top	Spiral	28,000	580	38,500	800
					Vertical	Double	55,000	1145	43,500	905
"B"	5.997	5.98	5	4822	Bottom	Cont.	29,500	615	44,000	915
					Top	Spiral	18,000	375	18,000	375
					Vertical	Comm.	25,000	520	32,000	665
"C"	6.013	5.64	3-1/2"	5523	Bottom	Transv.	12,000	250	20,500	425
					Top	Lug	6,000	125	7,000	145
					Vertical	Double	*	*	45,500	945
"D"	6.066	5.61	3-1/2"	5544	Bottom	Cont.	45,000	935	41,000	850
					Top	Spiral	27,000	560	27,000	560
					Vertical	Double	*	*	43,500	905
"E"	6.054	5.64	3-1/2"	5500	Bottom	Rev.	44,500	925	44,500	925
					Top	Spiral	27,000	560	32,000	665
					Vertical	Comm.	33,500	695	41,000	850
"F"	6.012	5.79	2-3/4"	5350	Bottom	Long.	15,000	310	25,500	530
					Top	Lug	9,000	185	11,000	230
					Vertical	Double	*	*	43,000	895
"G"	5.947	6.70	6	4633	Bottom	Cont.	*	*	43,000	895
					Top	Spiral	24,000	500	27,500	570
					Vertical	Comm.	40,000	830	37,000	770
"H"	5.947	6.45	6	4739	Bottom	Transv.	35,000	730	35,000	730
					Top	Lug	23,000	480	9,000	185

*No slippage indicated at 45,000 p.s.i.

RESULTS

There was little variation of the form of the Load - Slip curves for Series A, B, D, E, and G representing the prepared bars cast in the vertical and bottom horizontal positions. On the contrary the curves representing the top horizontal bars for these series vary rather widely. In Series B, D, and G, in particular, in which the double continuous spiral bar was employed, the curves representing each position of casting are, with one exception, quite similar. The exception is that representing the top horizontal bar in Series B.

There appears to be but little difference in the bond characteristics of the two types of commercial bars as used in Series C, F, and H. With exception of the bars cast vertically the results are relatively poor. This is especially true for the bars cast in the top horizontal position.

Although there has been only one set of specimens tested for each of the bars, No. 2 and No. 3, having the double reversed spiral ribs, results indicate that this type of bar may have a somewhat better bond resistance in the top position than do those with the continuous spiral.

With the limited number of tests being considered it appears that variations in the slump of the concrete had no marked influence upon the bond characteristics of the several types of bars.

It has been recommended that a good criterion of the bond strength of a bar subjected to the pull-out test is the resistance developed at a slip of 0.01 inch at the loaded end or 0.001 inch at the free end. These values expressed in both unit steel stress and unit bond stress are given in Table II and are represented graphically in Plate VII. Generally, a slip of 0.01 inch occurred in the prepared bars cast in the vertical and bottom horizontal positions before a slip of 0.001 inch was indicated at the free end. The opposite was true, with a few exceptions, for the prepared bars, cast in the top horizontal positions and for the commercial bars cast in all positions.